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Application technology of boron via foliar and its effects on cotton crop phenology

Tecnologia de aplicação de boron através de foliar e seus efeitos na fenologia da cultura de algodão

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ABSTRACT
Boron can be applied to cotton crops together with pesticides. Producers have allied medium and fine droplets to low application rates, which can lead to low boron deposition on the leaves. This work aimed to evaluate the spray deposition and absorption of boron leaf application on a cotton crop, by varying the surfactant and the application rate, comparing the effects on the crops' phenology and yield. Boron was applied using a backpack sprayer pressurized with CO2. Spray deposition was estimated based on the mass balance methodology. Plant leaves were collected for analysis at 17 days after application. The use and variation of the application technology affect micronutrient B absorption by leaf spray application. The application rate of 120 L ha-1 with siliconized surfactant adjuvant provides higher spray deposition on cotton plants and consequently higher boron absorption. The application rate of 70 L ha-1 without siliconized surfactant adjuvant provides lower boron absorption.

Keywords: agrochemicals application; micronutrient; yield.

RESUMO
O boro pode ser aplicado às lavouras de algodão junto com pesticidas. Os produtores aliaram gotas médias e finas a baixas taxas de aplicação, o que pode levar a baixa deposição de boro nas folhas. Este trabalho teve como objetivo avaliar a deposição por spray e absorção da aplicação de folhas de boro em uma cultura de algodão, variando o surfactante e a taxa de aplicação, comparando os efeitos na fenologia e produtividade das culturas. O boro foi aplicado usando um pulverizador de mochila pressurizado com CO2. A deposição de spray foi estimada com base na metodologia de balanço de massa. As folhas das plantas foram coletadas para análise aos 17 dias após a aplicação. O uso e a variação da tecnologia de aplicação afetam a absorção de micronutrientes B por aplicação de spray de folhas. A taxa de aplicação de 120 L ha-1 com adjuvante surfactante siliconizado proporciona maior deposição por pulverização em plantas de algodão e consequentemente maior absorção de boro. A taxa de aplicação de 70 L ha-1 sem adjuvante surfactante siliconizado proporciona menor absorção de boro.

Palavras-chave: aplicação de agroquímicos; micro nutriente; produção.

1 INTRODUCTION

Sowing of cotton in the second crop on Brazilian Cerrado is increasing lately. This practice occurs almost simultaneously with the soybean harvest as a primary crop. The average productivity of Brazilian cotton has grown due to the use of more productive cultivars, greater processing yield and fertilizer programs (FERREIRA *et al.*, 2015), as the application of micronutrients.

Micronutrients have been applied together with agrochemicals to the leaves of cotton crops. Instead of being applied by itself, this micronutrient is usually sprayed in conjunction with phytosanitary products, which, in turn, are commonly applied with surfactant adjuvant (GAZZIERO, 2015). Moreover, sprayed products are susceptible to spray drift (NUYTTENS *et al.*, 2017), and so, the micronutrients mixture together on the syrup.

Most foliar fertilizers are applied together with fungicides and insecticides using lower application rates as well as tips that provide fine droplets, favoring drift and evaporation losses (YADEGARI, 2016). This procedure leads to a high probability of lower micronutrient deposition and consequently lower foliar absorption due to problems in the correct use of the application technology.

Increasing this problematic scenario, the addition of surfactant adjuvants to the spray influences the application quality. The siliconized surfactant adjuvant stands out for decreasing the spray surface tension and increasing the spread of the drop on the leaf surface; however, it increases evaporation rate and the percentage of droplets smaller than 100 μm, which are more prone to drift (BAIO *et al.*, 2015). However, the use of a siliconized adjuvant favors the leaf absorption of the droplet (CAMOLESE e BAIO, 2016). Surfactants are commonly used in micronutrient leaf applications since it tends to improve the homogeneity of the mixture and the spray wettability

(GAZZIERO, 2015). Moreover, depending on the type, the adjuvant might reduce risks of drift and evaporation losses.

One of the primary sources of micronutrient boron (B) for the plant is via mineralization of soil organic matter. However, in soils of Cerrado, the soil content of this compound is relatively low. Boron is involved in many biochemical and physiological plant processes such as sugar translocation, membrane permeability, leaf photosynthesis, cell elongation and division, protein, amino acid and nitrate metabolism (YADEGARI, 2016). Boron also influences flower development, pollen germination, and fertilization.

Therefore, the use of sprayed micronutrients needs to be more studied. To illustrate that other factors are affecting micronutrients deposition and absorption, SILVA, M. *et al.* (2017) experimented the B application via foliar on green-beans and reported that it does not influence plant height, production components, and grain yield.

This work aimed to evaluate leaf deposits and absorption from boron application on a cotton crop by varying the siliconized surfactant adjuvant and the application rate and by comparing the effect of this variation on the crop's phenology and yield.

2 MATERIAL AND METHODS

This work was carried out in 2016 in the municipality of Chapadão do Céu/GO, in a field cropped with the cotton cultivar FM 975WS, at Fazenda Amambaí (18^{0}33'89"S, 52^{0}60'53"W, at approximately 850 m above sea level). The soil was classified as Dystrophic Red Latosol. Soil samples at 0.2 m depth were collected for analyses (macro and micronutrients).

The experiment design consisted of a randomized block with nine replications, in a 2x2 factorial scheme plus control treatment, with two application rates (70 and 120 L ha^{-1}), and presence and absence of surfactant adjuvant on the spray syrup. Thus, all treatment contained micronutrient boron applied; once, this study focused on the boron abortion varying the technique applied.

The sprayed deposits on the upper and lower strata of the plants were analyzed separately since higher deposition on the upper stratum is noticeable and expected (BAIO *et al.*, 2018). B leaf application at the supplemental dose of 1.0 kg ha^{-1} was performed at 45 DAE on all application technology treatments (application rates and surfactant addition), except on the control plot. Boric acid (H_3BO_3) was used as a micronutrient B source. The crop was at the F1 phenological stage (first open floral bud from the first fruiting branch) (MARUR e RUANO, 2001). The treatments were installed in 45 (36 plots plus nine control treatment) experimental plots of 4.8 x 10.0 m, totaling 48 m^2 per plot.

Cotton seeds were sown in January 2016, spaced at 0.80 m between rows, as a second crop (succession to beans), totaling a population of one hundred thousand plants per hectare. Sowing fertilization did not include micronutrients and consisted of 15 kg ha^{-1} of nitrogen and 81 kg ha^{-1} of phosphorus (on furrow) and 90 kg ha^{-1} of potassium chloride (top dressed previously on sowing). At 20 days after emergence (DAE), 22 kg ha^{-1} of nitrogen was applied as top-dressing. The other agricultural inputs were applied throughout plant development by the monitoring and standards for pests and diseases control in the region (FREIRE, 2015).

The spray syrup was applied using a backpack sprayer pressurized with CO_2 (Herbicat, Catanduva, Brasil), with 3 m of spray boom and six tips Jacto model ADI 11001, spaced 0.5 m apart. The displacement speed was 4 km h^{-1} (1.11 m s^{-1}) for all treatments. The spray application rate varied between 70 and 120 L ha^{-1}, adjusted by changing the hydraulic working pressure (200 kPa and 400 kPa, respectively), but maintaining the same droplet size class, as medium, according to the standard ASABE S572. Droplets spectra generated by the tip were evaluated using the particle size analyzer Spraytec (Malvern, England). The same equipment measured volume Median Diameter (VMD) and the relative amplitude of the droplet spectrum (Span index).

Leaf syrup deposits containing micronutrient B were estimated by the mass balance methodology (CAMOLESE e BAIO, 2016), using the tracer dye rhodamine B at a concentration of 40.0 and 23.3 mg L^{-1} (70 and 120 L ha^{-1} treatments, respectively, in order to have the same tracer dye concentration per area). Tracer dye can be efficiently used to evaluate spray deposition containing agrochemicals and quantify spray drift (ALVES *et al.*, 2014). The siliconized surfactant adjuvant Break Thru (Degussa Brazil) was used at a concentration of 0.01% (based on volume). The temperature of the air, relative humidity, and wind speed were monitored throughout the whole application process, using a portable digital anemometer (Instrutherm, model AD-250) and a thermo-hygrometer (Instrutemp, model TH802A).

The deposition analysis used three replications from the plants of the two central rows of the plot, totaling six trifoliate (three in the upper stratum; and three in the lower stratum of the plants). These samples were stored in 0.30 m x 0.20 m, adequately identified plastic bags. Spray deposit was extracted from the sampled leaf using 30 mL of distilled water solution and 1% Tween 80. The extracted lavage solution was subject to tracer concentration reading using the Trilogy fluorometer (Turner Designs, Sunnyvale, USA). The ImageJ 1.45 software (RASBAND, 2018) was used to determine the leaf area. Trifoliate were scanned on a 600 dpi resolution desktop scanner.

Reference leaves for the B leaf analysis and quantification of the B absorption were sampled at 17 days after application, by collecting the fifth wholly expanded leaf. The cotton yield of each experimental plot was estimated by collecting two-square-meter-mature fruits from the center of the plots, at the end of the crop cycle.

The variables analyzed according to the treatments were: deposition at upper plant stratum (D_U), deposition at lower stratum cotton (D_L) yield (Yield); leaf B concentration (B); weight of ten bolls (10B); plant height at 14 (H14D), 26 (H26D), 51 (H51D), 68 (H68D) and 82 (H82D) days after emergence (DAE); number of flowers per plant (F); number of branches per plant (Bran); and vegetation index (NDVI). NDVI was measured at 82 DAE over the two central rows using an active crop sensor Holland Scientific, Crop Circle ACS 470.

The analysis of discrepant data was applied to the normal distribution. Shapiro-Wilk normality test was used in all treatments. The Tukey's test performed means comparison at 5% significance level to the spray droplet spectrum and syrup spray deposition. The canonical variables were analyzed, and the Pearson's correlations between the variables were estimated using the Rbio software (BHERING, 2017). The correlation network was used to graphically express the functional relationship between the estimates of the correlation coefficients, in which the proximity between the nodes (traces) is proportional to the absolute value of the correlation between them.

3 RESULTS AND DISCUSSION

Environmental conditions were monitored during the application. The temperature ranged between 23.5º C and 25.4º C; the relative air humidity varied between 67% and 72%, and the wind speed alternated between 2.1 and 3.2 km h^{-1}. Thus, all climatic conditions were favorable to the spray application, minimizing the potential spray drift that could affect the differences between treatments (AL HEIDARY *et al.*, 2014). The rainfall information was 192.5 mm in January, 210.0 mm in February, 177.5 mm in March, 263.0 mm in April, and 37.5 mm in May. Thus, there was not a hydric restriction to the cotton development.

The mean VMD of the droplet spectra generated by the ADI 11001 tips working at 200 kPa and 400 kPa were 238.92 µm and 187.31 µm, respectively, characterized as medium-size droplets, as planned (Table 1). The decrease in droplet size is a consequence of increased hydraulic pressure, but it was not too high in order to change the droplet class size (175-250 µm - ASABE S572).

Table 1. Volume median diameter, relative amplitude, and percentage of droplets smaller than one hundred microns about treatments variation.

	VMD (µm)	Class Size	Span index	% Droplets < 100 µm
200 kPa water	237.47 a	medium	1.47 a	4.83 c
400 kPa water	187.08 b	medium	1.57 a	13.46 b
200 kPa surfactant	240.37 a	medium	1.43 a	5.28 c
400 kPa surfactant	187.54 b	medium	1.46 a	14.72 a
CV (%)	4.74		6.15	9.23
F test	53.83**		1.31**	267.32**

Means followed by different lowercase letters in the column differ from each other by the Tukey's test at 5% probability level. ** significant at 5% probability.

The mean Span index was 1.48 and did not vary about the pressure variation. This index, also known as relative amplitude, reports on the homogeneity of the droplet population. The lower the value, the more homogeneous is the droplet spectrum. The percentage of droplets smaller than 100 µm increased with the increase in the system pressure, as expected, showing a higher value with siliconized surfactant adjuvant addition.

According to the Figure 1, varying the application rate (70 and 120 L ha^{-1}) and the presence of adjuvant surfactant modify the syrup spray deposition on the upper and lower strata of the crop. The application rate of 120 L ha^{-1} without adjuvant provided higher spray deposition on the upper crop stratum. This fact can be explained by the higher amount of liquid applied per hectare; once there was not an obstacle to the droplet deposition at this stratum of the crop. The variability of the spray deposition obtained by the application rate of 120 L ha^{-1} with adjuvant is associated with the variability of the leaf boron absorption. Thus, the higher the application rate with the adjuvant promoted the higher boron absorption. The variability of the application rate of 70 L ha^{-1} without adjuvant was not associated with any response variable. This was the treatment with the lower deposition.

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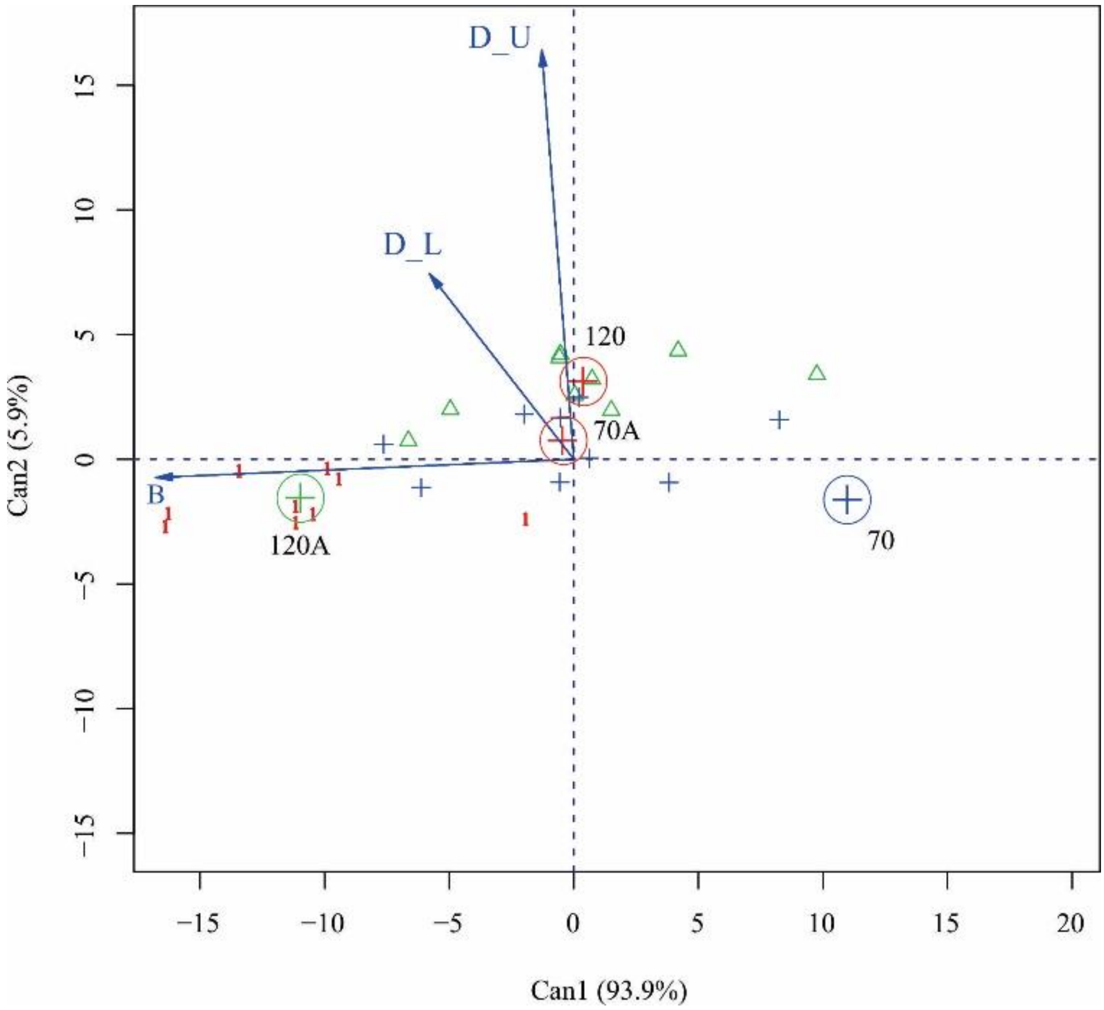

Figure 1. Canonical variables analysis for spray syrup deposition on upper and lower strata of the cotton plant (D_U and D_L), and leaf boron absorption (B) evaluated at 62 DAE, according to the application rates of 70 and 120 L ha^{-1}, and the presence (A) or absence of adjuvant on the syrup.

SOUZA *et al.* (2017) studied the effect of spray tips and application rates on the spray deposition in soybean and observed that the increase in the application rate resulted in higher spray deposition on the upper stratum of plants. CUNHA *et al.* (2017) evaluated the spray deposition on the soybean crop in function of spray tip and application rate and confirmed that even using different types of spray tips, the difficulty remains to reach the leaves located near to the lower third of the soybean crop.

However, the use of high application rates requires caution as they may cause spray saturation on the leaves, causing runoff. The high amount of liquid volumes on the leaf surface could cause runoff due to the maximum liquid retention capacity of the leaf (BAIO *et al.*, 2015). Therefore, product loss increases at specific application rates, leading to an uneven application.

Smaller droplets tend to undergo high losses due to evaporation and drift, and the use of siliconized surfactant potentiated these losses. GRIESANG *et al.* (2017) evaluated spray deposition of syrup with adjuvants and observed that the spray containing the compound presented higher drift levels when compared with sprays without adjuvant. The authors also reported that the use of the air-induction nozzle can reduce spray drift in 80%.

Aqueous solutions with surfactants resulted in a 20% shorter evaporation time when compared with only water (GIMENES *et al.*, 2013). The use of adjuvants offers excellent potential to improve the homogeneity of sprayed pesticides, to increase spray coverage and to reduce pesticide application rates on plants.

When analyzing the spray deposition on the lower stratum of cotton plants, the statistical difference between the application rates of 70 and 120 L ha^{-1} was observed only without surfactant on the syrup and at the application rate of 120 L ha^{-1}. The higher the application rate without siliconized adjuvant the higher the deposition. However, when the adjuvant was added on the syrup, the results are the opposite.

These results confirm that the higher micronutrient absorption occurred with, the higher spray deposition. Soil samples analyses of the experimental plots revealed a B concentration of 0.12 Mg dm^{-3} for the 0.00-0.20 m-depth layer and of 0.11 Mg dm^{-3} for the 0.20-0.40 m-depth layer. The siliconized adjuvant can decrease the surface tension of the droplets deposited on the leaf surface and increased the wet area (BAIO *et al.*, 2015), allowing a faster micronutrient B absorption. Therefore, low application rates deserve attention as they can lead to significant micronutrients losses by droplets evaporation and drift, which consequently reduce nutrient absorption.

A positive correlation of high magnitude was detected between NDVI and the cotton plant height at 68 DAE (Figure 2), given by the thickness of the trace. This result indicates that the higher the plant mass, in function of the higher NDVI values, the higher is the plant height. There was a direct correlation between leaf boron absorption and cotton yield, and plant height at 68 DAE as well. The number of branches per cotton plan can also be associated with the variability of boron absorption but in a lower effect. The similarity might have been due to the appropriate B levels in the experimental plots since the crop requires small quantities of the nutrient.

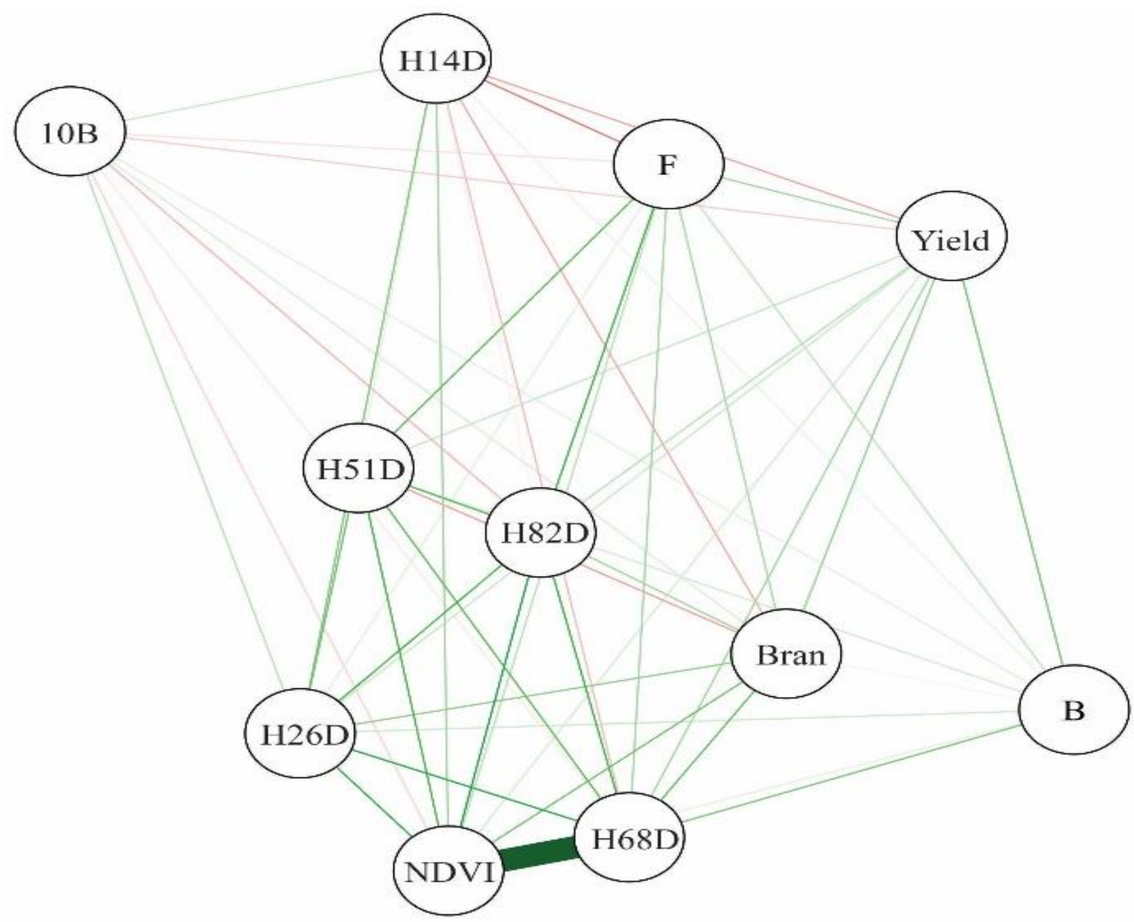

Figure 2. Pearson's correlation network between the variables: cotton yield (Yield); leaf boron concentration (B); weight of ten bolls (10B); plant height at 14 DAE (H14D), 26 (H26D), 51 (H51D), 68 (H68D) and 82 DAE (H82D); number of flowers per plant (F); number of branches per plant (Bran); and vegetation index (NDVI).

ALBUQUERQUE *et al.* (2014) analyzed the effect of zinc and boron application on the growth of upland cotton BRS-201 under field conditions and reported no increase in cotton plant growth at 30 and 60 DAE. Conversely, BOGIANI *et al.* (2014) evaluated the absorption and mobility of boron in cotton cultivars and concluded that boron deficiency impairs plants physiological activities and growth, regardless of the presence of symptoms.

The B applied affected the total number of branches in cotton plants (Figure 3), showing the difference for the number of branches observed with the application rates of 120 and 70 L ha^{-1} with adjuvant and 120 L ha^{-1} without adjuvant, when compared with the control treatment and the application rate of 70 L ha^{-1}. Boron application influences the quantity between reproductive and vegetative branches (BOGIANI *et al.*, 2014). Boron deficiency results in the more significant vegetative branches formation, which can be explained by the disturbances in the physiology of the reproductive development (YADEGARI, 2016). Also, the supplemental micronutrient B application positively affected the weight of ten bolls and the plant height at 68 DAE. SILVA, E. S. *et al.* (2017) reported that the best values of length, strength, color fiber degree, were obtained with a quantitative of 1.25 kg ha^{-1} of boron.

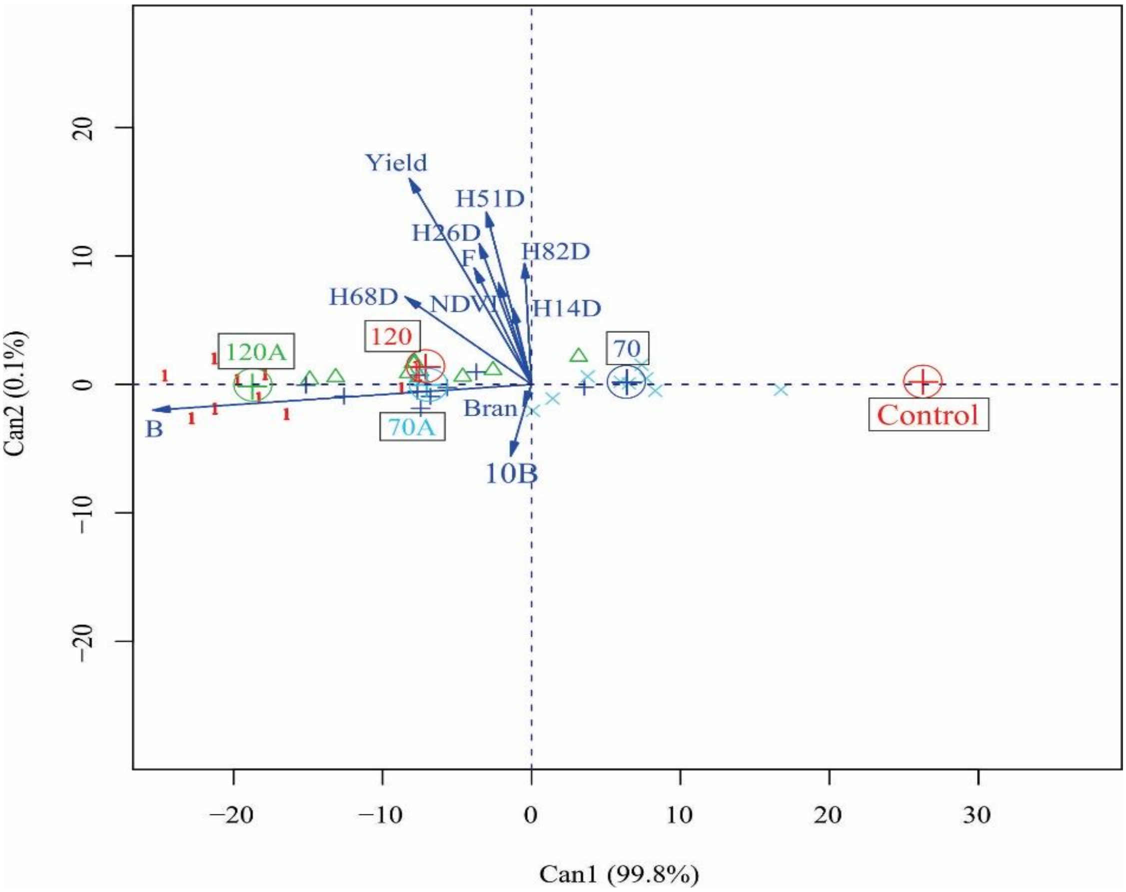

Figure 3. Canonical variables analysis for the variables: cotton yield (Yield); leaf boron concentration (B); weight of ten bolls (10B); plant height at 14 DAE (H14D), 26 (H26D), 51 (H51D), 68 (H68D) and 82 DAE (H82D); number of flowers per plant (F); number of branches per plant (Bran); and vegetation index (NDVI); and the treatments: application rates 70 and 120 L ha^{-1}; and the presence (A) or absence of adjuvant on the syrup.

The treatment with an application rate of 120 L ha^{-1} without surfactant was statistically different from that with an application rate of 70 L ha^{-1} without surfactant and from the control treatment. Thus, increasing the application rate lead to increase the boron absorption and they were different to the control treatment, without any boron applied, only supplied via soil. The control treatment (no micronutrient B application) did not show deficiency symptoms, confirming that the soil presented enough micronutrient B levels.

A lower number of floral buds was found at lower B concentration, since plants deficient at this micronutrient present disturbances in the vascular system of the peduncle region, which may hinder the necessary transport of carbohydrates to these organs, causing abortion (LI *et al.*, 2017). Cotton plants treated with low boron doses presented smaller quantities of reproductive structures and greater abortion (with blight symptoms, a characteristic of B deficiency) (BOGIANI *et al.*, 2014; LI *et al.*, 2017).

The variability of the cotton yield presented the higher association with cotton plant height than B absorption. GANDAHI *et al.* (2016) studied the response of cotton yield production to boron and zinc application and confirmed that boron application alone, regardless if via solid fertilizer or leaf application, does not significantly affect crop yield in case of micronutrients deficiencies.

4 CONCLUSIONS

The use and variation of the application technology affect micronutrient B absorption by leaf spray application.

The application rate of 120 L ha^{-1} with siliconized surfactant adjuvant provides higher spray deposition on cotton plants and consequently higher boron absorption.

The application rate of 70 L ha^{-1} without siliconized surfactant adjuvant provides lower boron absorption.

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